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Exploring economically and environmentally viable northeastern US dairy farm strategies for coping with rising corn grain prices

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ABSTRACT

In 2008, corn grain prices rose \$115/t of DM above the 2005 average. Such an increase creates tight marginal profits for small (<100) and medium-sized (100 to 199) dairy farms in the northeastern United States importing corn grain as animal feed supplement. Particularly in New York State, dairy farmers are attempting to avoid or minimize profit losses by growing more corn silage and reducing corn grain purchases. This study applies the Integrated Farm Systems Model to 1 small and 1 medium-sized New York State dairy farm to predict 1) sediment and P loss impacts from expanding corn fields, 2) benefits of no-till or cover cropping on corn fields, and 3) alternatives to the economic challenge of the current farming system as the price ratio of milk to corn grain continues to decline. Based on the simulation results, expanding corn silage production by 3% of the cultivated farm area increased sediment and sediment-bound P losses by 41 and 18%, respectively. Implementing no-till controlled about 84% of the erosion and about 75% of the sediment-bound P that would have occurred from the conventionally tilled, expanded corn production scenario. Implementing a conventionally tilled cover crop with the conventionally tilled, expanded corn production scenario controlled both erosion and sediment-bound P, but to a lesser extent than no-till corn with no cover crop. However, annual farm net return using cover crops was slightly less than when using no-till. Increasing on-farm grass productivity while feeding cows a high-quality, high-forage diet and precise dietary P levels offered dual benefits: 1) improved farm profitability from reduced purchases of dietary protein and P supplements, and 2) decreased runoff P losses from reduced P-levels in applied manure. Moreover, alternatives such as growing additional small grains on marginal lands and increasing milk production levels demonstrated great potential in increasing farm profitability. Overall, it is crucial that conservation measures such as no-till and cover cropping be implemented on new or existing corn lands as these areas often pose the highest threat for P losses through runoff. Although alternatives that would likely provide the largest net profit were evaluated one at a time to better quantify their individual impacts, combinations of these strategies, such as no-till corn plus a minimum-till cover crop, are recommended whenever feasible.

Key words: forage management, no-till, phosphorus, simulation

INTRODUCTION

Increasing prices for corn grain and fuel have negatively affected profit margins for farmers throughout the northeastern United States. In particular, New York corn grain purchase prices increased from \$90.16/t of DM in 2005 to \$205.12/t of DM in 2008 (USDA-NASS, 2008a,b), and diesel fuel prices in the Northeast rose by about \$0.40/L (EIA, 2008). Although gasoline and other cost-of-living differentials may decline in the long term, decreasing milk to feed price ratios (USDA-NASS, 2008b) support the need for major shifts in thinking and practice among dairy farmers.

Corn area in the United States increased by 19 and 10% in 2007 and 2008, respectively, compared with corn area planted in 2006 (USDA-NRCS, 2008). The increase in corn area and the corresponding increase in fertilizer application are detrimental to downstream waters, many of which are already nutrient-stressed (Simpson et al., 2008). New York State dairy farmers are beginning to move small quantities of good quality grassland into corn production and transition more marginal, uncultivated land into grassland. From 2005 to 2007, the increases in areas of total corn harvested in New York State and in Delaware County (NY) were 26,305 ha (7%) and 283 ha (10%), respectively (USDA-NASS, 2008c). In Delaware County, in particular, about 70% of corn area was harvested as silage. Typically, corn silage has a higher yield of energy and DM per

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hectare compared with hay crop silage, whether grass or alfalfa. By expanding corn production, farmers are striving to meet their herds' feed energy needs through on-farm production and reclaim as much profit margin as possible by reducing costs on grain feed purchases.

Unfortunately, erosion and associated P loadings from corn land are of particular environmental concern. A modeling study of the Cannonsville Reservoir Watershed, which incorporates this study area, reported that 58% of the watershed P loss comes from corn production land that, in turn, represents only 1.2% of the total watershed (Tolson and Shoemaker, 2004). Historically, tillage methods that minimally disrupt the soil have not been widely adopted in the New York Southern Tier. This was due in part to soil types not being suitable to early minimum-tillage machinery and in part due to the prohibitive expense of newer minimum-tillage machinery for small farms. As a result, significant proportions of the area's agricultural erosion and sediment-bound P have come from the high proportions of soil left uncovered by growing continuously tilled corn crops. These losses, added to losses from high levels of soil-P (Delaware County Watershed Affairs, 2002; Ketterings et al., 2005), due in part to years of overfeeding P in feed supplements (Dou et al., 2003; Cerosaletti et al., 2004), contribute substantial P loading to New York City's water supply reservoirs.

Cornell University Cooperative Extension of Delaware County (**CCE**) has developed and promoted a set of management practices, called the Precision Feed and Forage Management (**PFM**) program, which directly targets the root cause of P buildup on farms (CCE, 2008). This program reduces the farm-level P balance by reducing P imported in feed rations to meet NRC recommendations and by improving production, quality, and use of on-farm forage. Additionally, PFM aims to convert as much corn land to grass as possible while meeting herd energy needs. Together, these efforts reduce P excreted in manure, promote recycling and reuse of P on the farm, and reduce erosion and associated nutrient losses from farm fields, particularly those previously in corn silage production (Cerosaletti et al., 2004; Ghebremichael et al., 2007). The PFM program is seeing increased acceptance as implementations on several farms have demonstrated positive results that often enhance farm economic returns to improve farm viability. In conjunction with this program, CCE personnel have successfully implemented minimum-tillage, custom-operator programs in Delaware County. Based on recent seasons of acceptable corn yields from no-tilled fields, more farmers are considering no-till planting as a viable management practice for growing corn silage (CCE, 2008). The current study builds on the demonstrated willingness and action by Delaware County farmers to consider alternative management practices by considering a variety of well established, practical methods for reducing soil and P losses.

The 2007 Census of Agriculture data indicated that the dairy farms in Delaware County averaged 67 cows with average and median farm sizes of 90 and 81 ha, respectively (USDA-NASS, 2009a). The data also indicated that nearly 84 and 15% of Delaware County dairy farms were small (<100 cows) or medium-sized (100 to 199 cows), respectively. These 2 herd groups make up 68% of the county's dairy cow population. The 2 dairy farms in this study, having about 50 and 100 milk cows, are representative dairy farms for smaller and medium-sized farms in the area, which comprise the majority of the county's dairy sector.

Small and medium-sized dairy farms are an important part of the dairy sector not only in New York State but also throughout the northeastern United States (CT, ME, MD, MA, NH, NJ, NY, NC, PA, RI, SC, VT, VA, and WV). Approximately 78 and 14% of the Northeast's dairy farms have <100 cows and between 100 and 199 cows, respectively (USDA-NASS, 2009b). As these farms contain about 42 and 27% of the region's total dairy herd, nearly 70% of the region's dairy cows are managed on small and medium-sized dairy farms. Moreover, these farms contribute 59% of the dairy products sold by the Northeast's dairy farms (USDA-NASS, 2009b). Clearly, small and medium-sized farming are vital to the economy and dairy farming community in the northeastern United States.

The overriding objective of this study was to determine practical, alternative farm strategies that would enable farmers of small and medium-sized dairies in the northeastern United States to maintain profitability without negatively affecting off-farm soil and water quality. This was accomplished through 3 tasks: 1) quantify expected environmental and economic effects of increased area in corn production, 2) quantify environmental and economic benefits of no-till and cover-crop management options on corn land, and 3) explore and assess environmental and economical benefits of the other farm strategies including increased milk production, producing small grains for supplementation in the ration, and implementing PFM.

MATERIALS AND METHODS

Model Description

The Integrated Farm Systems Model (**IFSM**) Version 2.1 by Rotz et al. (2007) is a comprehensive farm-scale model that simulates long-term farm performance, profitability, and potential nutrient accumulation and loss to the environment. Within IFSM, feed use is optimized to make sure the cheapest homegrown feeds available on-farm are used while meeting livestock dietary needs and adhering to labor and machinery constraints. By simulating various farm strategies in IFSM and comparing results, relative environmental and economic effects of the various strategies on the whole-farm system can be evaluated. The IFSM has been successfully used to evaluate economic and environmental statuses of farming systems in the northeastern United States (Sanderson et al., 2001; Soder and Rotz, 2001; Rotz et al., 2002; Ghebremichael et al., 2007).

Farm Descriptions

The IFSM was applied to the 2 dairy farms, identified as R-farm and W-farm, located in the upper half of the Cannonsville Reservoir Watershed in Delaware County. Both farms are on predominantly shallow silt loam soils with fragipans and moderately steep slopes averaging 8 to 15%. At the time of the study, the medium-sized R-farm consisted of 120 ha of cultivated crop area, including 12 ha of corn for silage, and maintained about 100 lactating Holsteins housed in a tie-stall barn. Milk yield of the farm averaged 8,966 L/yr per cow. The smaller W-farm contained about 95 ha of cultivated crop area, including 8 ha of corn for silage, and maintained about 50 lactating Holsteins housed in a tie-stall barn. Milk yield averaged 6,413 L/yr per cow. In addition, R-farm and W-farm have about 12 and 8 ha, respectively, of marginal land that is not typically put into production. Whole-farm system descriptions of both farms as well as farming characteristics of the region are described in detail in Ghebremichael et al. (2007). These 2 farms were chosen for the study as they have been gracious cooperators with CCE personnel before and after their participation in the PFM program (Cerosaletti et al., 2004). As such, they have provided detailed verification data for the baseline and basic PFM alternative scenarios simulated with IFSM in our previous study (Ghebremichael et al., 2007).

Baseline Model Representations and Verifications

The IFSM representations of the baseline scenarios for the 2 study farms were extensively verified in Ghebremichael et al. (2007). A synopsis of these results follows. The IFSM input data needed to represent the study farms included data regarding farm characteristics, machinery, and weather. The farm characteristics data consist of detailed information including crop types and extents, main soil type and slope, type of dairy cows, numbers of cows of different ages, manure handling strategies, and equipment and structures used in managing the livestock and crops. The machinery input includes data related to machine type, size, hours of use, and associated costs. For both farm and machinery data, actual data gathered by CCE personnel from the study farms were used. Economic data includes prices of farm commodities produced, purchased feeds, and farm products sold off-farm. These data were obtained from CCE personnel and the National Agricultural Statistics Service. Weather data used included daily values of total precipitation, maximum and minimum temperatures, and solar radiation. These data were obtained from National Climate Data Center database for the closest station (NY Delhi station) to the study farms. For the 2 study farms, IFSM simulation of average annual predictions was performed using 25 yr of this historical weather data. The model evaluates the performance of a farm enterprise by predicting crop yield and quality; on-farm feed, milk, and manure produced; feeds sold and/or supplemental feeds purchased; and resources expended, such as labor, fuel, and equipment used. These simulated farm performances were compared with the actual data for verification purposes. Predicted average crop yields and nutritive contents were closely matched with crop yield data collected from farm records. For example, predicted annual corn silage yield for R-farm of 161 t closely matched that farm's average observed annual yield of 163 t of DM. Similarly, the predicted corn silage yield of 63 t of DM closely matched the average observed yield of 60 t of DM for the W-farm. In addition, IFSM predictions of feed use, production, and purchases for the study farms were compared with the actual farm metrics and found to be comparable to actual values. Other model-simulated factors verified successfully with actual farm records include long-term P balances (P imported – P exported), production costs, and net returns. Overall, based on actual farm records, IFSM was able to represent the baseline performance of the study farms in predicting crop yield and quality; on-farm feed used and milk produced; feeds sold and/or supplemental feeds purchased; and resources expended, such as cost of production and farm net returns.

Strategy Descriptions

Strategies were developed by considering Delaware County farmers' actions in response to corn and fuel prices. The main changes that farmers began to pursue involved increasing corn silage hectares, adopting no-till management, or substituting small grains for corn grain in the ration. A single management change was made in each simulation scenario to enable determination of individual effects of each management change on the farms. Farm strategy descriptions are presented in Table 1.

Table 1. Outline of farm system factors changed within each alternative management strategy[1]

Strategy	Baseline			Alternative scenarios						
	2005	2008	2008X	X+notill	X+cover	+smgrn	+milk	+PFM	X+PFM	Grass+PFM
Corn price increased		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Expanded corn silage production			Yes	Yes	Yes				Yes	
Corn silage switched from conventionally tilled to no-till				Yes						
Conventionally tilled, winter rye cover added to conventionally tilled corn					Yes					
Marginal land sown in no-till oats						Yes				
Milk production increased by 5%							Yes			
Precision feed and forage management enforced								Yes	Yes	Yes
All corn land converted to grass										Yes

[1]Base2005 = 2005 corn price; Base2008 = Base2005 + corn price increase; Base2008X = Base2008 + corn area expanded; X+notill = Base2008X+ no-till management on corn crops; X+cover = Base2008X + cover crop management on corn crops; +smgrn = Base2008 + small grain produced on marginal lands; +milk = Base2008 + 5% milk production increase; +PFM = Base2008 + precision feed management (high-quality forage production, high-forage diet, and reduction of dietary P); X+PFM = +PFM + corn area expanded; Grass+PFM = +PFM + corn fields converted to grass.

Base2005. This baseline scenario simulates the 2 farms based on their real-life, average economic and environmental conditions before implementation of any changes related to corn prices, corn area expansion, PFM, or other management strategies. Average 2005 corn grain prices of \$90.16/t of DM were used.

Base2008. This baseline scenario assesses the economic impact of increased corn grain prices on farm profitability. The corn grain price was increased by \$115/t of DM from Base2005's price of \$90.16/t of DM to the average monthly price from April to August 2008 of \$205.12/t of DM (USDA-NASS, 2008a,b). Adjustments were also made to prices of milk, protein feed, fertilizer, and fuel. All other farm data were kept the same as in Base2005.

Milk prices averaged \$33.40/hL from 1998 to 2005, whereas the average monthly price from April to August 2008 was \$42.50/hL (USDA-NASS, 2008b). Soybean meal increased by 143% from Base2005's price of \$245.20/t of DM (USDA-NASS, 2008d) to an average monthly price from April to July 2008 of \$595.70/t of DM (USDA-ERS, 2008a). Fertilizer price also increased between 1998 and 2007 (USDA-ERS, 2008b). Average prices of anhydrous ammonia and urea, sources of N in fertilizer production, were \$346.20 and \$263.50/t, respectively, during 1998 to 2005. These prices increased to \$576.60 and \$499.45/t, respectively, during 2007, an average increase of 78% (67 and 90% for anhydrous ammonia and urea, respectively). For P fertilizer sources, the price increase of super phosphate (44 to 46% phosphate) and diammonium phosphate (18–46–0) averaged 69% from 1998 to 2005 to 2007. Average prices of super phosphate and diammonium phosphate during 1998 to 2005 were \$276.70 and \$285.55/t, and increased to \$460.85 and \$487.30/t, respectively, during 2007. Based on these data, average increases of 78 and 69% were applied to the Base2005's prices of N and P fertilizers. Additionally, the price of diesel fuel increased from a 1998–2005 average price of \$0.40/L to \$1.10/L in April 2008, an increase of \$0.70/L (EIA, 2008).

Base2008X. This scenario assesses the expected environmental impacts and economic benefits from increased area in corn production under 2008 prices. Many New York farms have expanded their planting of corn for silage by 2 to 4 ha in an attempt to purchase less corn grain. These farmers use fields previously maintained in high-quality grass or steep, rocky fields that are acceptable for corn but are more challenging to work. In these fields, the recent opportunities for no-till planting, provided through CCE programs, have enabled corn planting on fields too rocky for efficient conventional-till planting. Corn area was expanded by 4 ha for R-farm and 3 ha for W-farm; all other farm data were kept the same as in Base2008.

X+notill. A no-till management practice was imposed on all existing and expanded corn fields from Base2008X by omitting tillage operations used in corn fields. No-till practices tend to reduce soil erosion, improve soil physical structure, conserve soil water, and restore organic matter (Lal et al., 2004; Wright and Hons, 2004). No-till has also been reported to potentially reduce atmospheric CO_2 through increased carbon sequestration (Bossuyt et al., 2002; Caldeira et al., 2004). Moreover, rising costs of energy and fuel provide an economic incentive to reduce tractor use wherever possible. All other conditions were kept the same as in Base2008X.

X+cover. This scenario assesses the expected environmental benefits of planting cover crops on bare corn fields during the fall and winter seasons. Reported benefits of cover crops include reduced transport of sediment from fields (Mutchler and McDowell, 1990; Dabney et al., 2001) and increased nutrient use efficiencies (Reicosky and Forcella, 1998). Mowing versus other mechanical methods of killing the cover crop has been shown to improve soil moisture and timing of cover crop N release with respect to corn N needs and lessen regrowth. In this scenario, winter rye was planted on all corn fields from Base2008X as a cover crop. These cover crops were mowed and residues were left on the ground as mulch. The soil was conventionally tilled and conditioned directly before the corn was planted. All other conditions were kept the same as Base2008X.

+smgrn. Producing small grain on marginal lands of Base2008 was considered as an alternative to expanding corn land (Base2008X). For this study, oat grain was selected over other small grains because it is has been found to grow well in the cool, moist climates and lower soil pH levels (acidic glacial tills) that are common to Delaware County. Areas used for corn silage or any other production purposes were not altered from Base2008. Instead, marginal areas of 12 and 8 ha, respectively, for R-farm and W-farm were placed into oat grain production for use as supplementary feed. In New York, more land is available for oat grain production than for expanding corn silage production because oat grains require relatively lower land quality compared with corn. The proposed increase in oat grain production is especially beneficial to farms that do not have additional suitable land available for corn production. By producing oat grains on marginal lands and substituting oat grains for corn grain in the feed, farms can purchase less high-priced corn grain. No-till practice was employed for oat establishment.

+milk. Increasing milk production of Base2008 was considered as a means of increasing net return of the farm. Based on feedback of CCE personnel, who have worked closely with these farmers, a 5% milk production increase was a level that could be potentially achieved by farms in the region, if they chose to focus efforts in that direction. The milk production level of R-farm was increased from 8,966 to 9,414 L/yr per cow. For W-farm, milk production was increased from 6,413 to 6,734 L/yr per cow. On average, cows in R-farm and W-farm were allowed to consume 0.4 and 0.6 kg/d, respectively, more purchased corn grain in their diet compared with those on Base2008 diets to achieve increased milk production levels. Additional assumptions made, though not explicitly modeled, were the use of more production-focused management techniques, such as robust or long day lighting and increased milking frequency. In both farms, on-farm produced feeds and any forage sold off-farm were kept the same as in Base2008.

+PFM. Following CCE guidelines, this PFM-based scenario involved increasing grass productivity, feeding cows a high-forage diet, and reducing dietary P levels for dairy cattle by 22% from the baseline scenario to match P levels recommended for dairy animals by the National Research Council (NRC, 2001). As detailed in Ghebremichael et al. (2007), rates of N fertilizer and the number of cuttings for hay harvest were increased to increase the yield and quality of grass production. By utilizing forage produced on-farm as much as possible and purchasing supplemental concentrates only as needed, the IFSM formulated rations with 48 and 61% more forage than those of the Base2008 (for R-farm and W-farm, respectively). Through daily process-level calculations, IFSM ensures that the rations, although high-forage, remain within the limits of what the rumen can handle and that all dietary needs are met. This scenario applies the PFM program to Base2008; thus, it includes the 2008 corn grain prices but not the expanded corn land.

X+PFM. This scenario combines Base2008X and +PFM by adding the expanded corn area of 4 ha for R-farm and 3 ha for W-farm while applying PFM strategies over the entire farm. This scenario assesses the economic benefits and environmental impacts of corn area expansion on farms that have already implemented PFM strategies. As in +PFM, cows were fed higher forage diets that were achieved in part by feeding more corn silage produced on-farm and reducing the amounts of purchased corn grain.

Grass+PFM. This scenario represents a high-productivity grass-based farming practice similar to +PFM, except that all corn fields were converted to grass production in an effort to reduce erosion and associated P losses from land used in production of corn silage. The cows in both farms were fed with high-quality forage consisting of only grass and alfalfa. The IFSM necessarily purchased more corn grain than in the +PFM to offset energy lost from a diet without corn silage. This scenario implicitly contrasts the economic effects of relying on purchased grain imports and environmental benefits reducing off-farm sediment and sediment-bound P losses due to row crops.

RESULTS AND DISCUSSION

Main farm factors evaluated included farm profits, feed imports, farm P balance, and P losses. These factors were compared across strategies within a farm to determine the relative success of each strategy in meeting the study objective for that farm. Comparisons across farms were made to a much lesser extent in light of differences between farms, such as physical characteristics, mission, economic assets, and personal preferences. The results of the strategies have been evaluated within 4 categories of the whole-farm system: feed production, feed utilization, economic impacts, and environmental impacts. Data related to feed production and utilization are presented in Tables 2 and 3. Data related to economic and environmental impacts of all farm strategies are presented in Tables 4 and 5.

Feed Production

With expanded land for corn silage (Base2008X, X+notill, or X+cover), annual corn silage production increased by about 36%, providing an additional 0.53 t DM and 0.46 t DM of corn silage per cow for R-farm and W-farm, respectively (Table 2). As a result, annual corn grain purchases decreased by 24% for each farm.

Oat production on marginal lands (+smgrn) reduced corn grain purchases by 20% for R-farm and by 56% for W-farm (Table 2). Although producing a small grain on the marginal land did not completely replace the amount of corn grain purchased by each farm to supplement the cow's diet, it did contribute toward the animals' energy needs and reduce off-farm purchases.

To achieve a 5% increase in milk production levels (+milk), no changes in feed production were made. However, corn grain purchases increased by 9 and 26% for R-farm and W-farm, respectively.

The PFM-based scenarios (+PFM, X+PFM, and Grass+PFM) decreased the amount of imported feed protein and dietary P supplements by increasing the amount and quality of homegrown forage and by reducing dietary P levels to match NRC recommendations. Production of grass forage (silage + hay) for +PFM increased from Base2008 by 43% (136 t of DM) for R-farm and 41% (72 t of DM) for W-farm (Table 2). Because of increasing forage productivity and the proportion of forage in the diet, total feed and supplement purchases decreased by 37 and 50% for R-farm and W-farm, respectively. In particular, annual purchases of protein concentrate declined by 106 t for R-farm and 61 t for W-farm (Table 2).

When corn area was expanded by 4 ha for R-farm and 3 ha for W-farm in addition to PFM management changes (X+PFM), 29 and 61% less corn grain was purchased for R-farm and W-farm than with the PFM changes alone (+PFM). The reduction achieved in corn grain purchases in X+PFM over +PFM was greater than the reduction of corn grain purchases achieved by putting additional land into corn production in Base2008X (with no PFM strategies) over Base2008. This was because of the improved grass crop quality and feeding rate of the PFM scenarios compared with the Base2005, Base2008, and Base2008X scenarios. Because more grain was required to achieve the milk production levels in the baseline than in the PFM-based scenarios, the increased corn silage yield in Base2008X still replaced less corn grain than it did in the 2 corn-growing PFM-based scenarios. Results are expected to be different if corn in the expanded land could be produced as grain rather than as silage. However, the short growing season of these farms makes harvest of quality corn grain a high-risk option.

Grass+PFM simulated total corn grain supplement purchases required to maintain the baseline milk production level for farms that have already implemented PFM and additionally convert all corn land to grass. In this scenario, the grass forage productivity rate was kept the same as in +PFM. By converting all corn land (12 ha for R-farm and 8 ha for W-farm) to high-productivity grass, high-quality forage production increased 23% on each farm. With all corn fields converted to grass, corn grain purchases increased by 8% for R-farm and 17% for W-farm to offset the reduction in available feed energy.

Feed Utilization

Growing additional corn silage (Base2008X) provided increased dietary forage of about 6% for R-farm and 3% for W-farm compared with Base2008 (Table 3). Additionally, the added corn silage provided dietary energy, which could replace some of the energy otherwise provided by corn grain. Although W-farm fed less corn grain per cow per day in the baseline than did R-farm, both farms purchased about 25% less grain respectively after producing more corn silage.

Producing oats on marginal lands of the farms (+smgrn) also enabled the farms to reduce the amount of corn grain purchases needed to supplement the diet, particularly during winter feeding periods when the oats were fed. Winter-period purchased corn grain supplements, compared with Base2008, were reduced by 45% (2.9 kg/d) and 56% (0.9 kg/d) for R-farm and

Table 2. Integrated Farm Systems Model-simulated, average annual crop yields, nutritive contents, and feed production and utilization for all strategies[1]

	R-farm (102 cows)									W-farm (52 cows)								
Item	2005, 2008	2008 X	X+ notill	X+ cover	+ smgrn	+ milk	+ PFM	X+ PFM	Grass +PFM	2005, 2008	2008 X	X+ notill	X+ cover	+ smgrn	+ milk	+ PFM	X+ PFM	Grass +PFM
Alfalfa, ha	9	9	9	9	9	9	9	9	9	16	16	16	16	16	16	16	16	16
Harvested grass, ha	63	63	63	63	63	63	63	63	75	48	48	48	48	48	48	48	48	56
CP, % of DM	18.5	18.3	18.3	18.3	18.4	18.5	19.0	19.0	19.0	18.0	18.0	18.0	18.0	18.0	18.0	19.0	19.0	19.0
NDF, % of DM	49.6	49.6	49.6	49.6	49.5	49.6	49.0	49.0	49.0	50.4	50.4	50.4	50.4	50.4	50.4	49.0	49.0	49.0
Forage produced, t of DM	313	307	309	311	316	315	449	453	549	175	174	174	174	174	175	247	246	305
Forage sold, t of DM	43	42	43	42	40	42	41	43	0	0	0	0	0	0	0	0	0	0
Pasture, ha	36	36	36	36	36	36	36	36	36	22	22	22	22	22	22	22	22	22
Yield, t of DM	182	182	182	181	181	185	181	182	182	73	74	74	74	73	73	73	74	73
Corn silage, ha	12	16	16	16	12	12	12	16	0	8	11	11	11	8	8	8	11	0
Yield, t of DM	161	215	219	218	161	161	161	215		63	87	88	87	64	63	63	87	
CP, % of DM	9	10	10	10	9	9	9	9		9	10	10	10	9	9	9	9	
NDF, % of DM	46	46	46	46	46	46	46	46		45	45	45	45	45	45	45	45	
Oat grain, ha					12									8				
Yield, t of DM (CP = 13%, NDF = 32%)					29									18				
Marginal land, uncultivated, ha	12	8	8	8	0	12	12	8	12	8	5	5	5	0	8	8	5	8
Purchased protein supplement, t of DM	139	139	139	139	139	139	33	36	29	81	81	81	81	82	81	20	17	18
Purchased corn grain, t of DM	195	151	151	150	156	212	177	125	191	34	26	26	26	15	43	36	14	42
Purchased vitamin and minerals, t	9	9	9	9	9	9	7	7	7	4	4	4	4	4	4	3	3	3
Milk production,[2] kg/yr per cow	8,966	8,966	8,966	8,966	8,966	9,414	8,966	8,966	8,966	6,413	6,413	6,413	6,413	6,413	6,734	6,413	6,413	6,413
Milk production, kg/d per cow	33	33	33	33	33	35	33	33	33	24	24	24	24	24	25	24	24	24

[1]Base2005 = 2005 corn price; Base2008 = Base2005 + corn price increase; Base2008X = Base2008 + corn area expanded; X+notill = Base2008X + no-till management on corn crops; X+cover = Base2008X + cover crop management on corn crops; +smgrn = Base2008 + small grain produced on marginal lands; +milk = Base2008 + 5% milk production increase; +PFM = Base2008 + precision feed management (high-quality forage production, high-forage diet, and reduction of dietary P); X+PFM = +PFM + corn area expanded; Grass+PFM = +PFM + corn fields converted to grass.

[2]Average BW = 684 kg for R-farm, 638 kg for W-farm; average milkfat = 3.7%.

Table 3. Integrated Farm Systems Model-predicted average daily feed composition of lactating cow diets for winter (November to March) and non-winter (April to October) of a typical year, for strategies in which forage percentages changed[1]

	R-farm (102 cows)							W-farm (52 cows)						
Item	2005, 2008	2008X	+smgrn	+milk	+PFM	X+PFM	Grass +PFM	2005, 2008	2008X	+smgrn	+milk	+PFM	X+PFM	Grass +PFM
Winter feeds														
Total feed intake, kg/d	20.4	20.7	19.9	21.0	20.7	21.0	20.1	17.0	17.1	17.0	17.1	17.9	17.5	18.4
Grazed forage	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Silage/hay	6.4	6.4	6.2	6.4	9.6	9.4	12.0	6.5	6.7	6.5	6.5	10.8	10.2	14.9
Corn silage	3.3	4.9	3.6	3.6	3.3	7.5	0.0	3.3	4.2	3.3	3.5	4.2	6.3	0.0
Oat grain	—	—	2.4	—	—	—	—	—	—	1.0	—	—	—	—
Purchased corn grain	6.4	5.0	3.5	6.7	6.5	2.3	7.0	1.6	1.2	0.7	2.1	1.4	0.4	2.3
Purchased protein supplement	4.3	4.3	4.3	4.3	1.3	1.9	1.1	5.0	5.0	5.0	5.0	1.5	1.5	1.2
Forage portion of diet, %	48	55	49	48	63	80	60	61	64	61	58	82	89	81
Non-winter feeds														
Total feed intake, kg/d	20.6	21.1	21.0	21.6	21.0	21.2	20.4	16.9	17.2	16.9	17.3	17.4	17.5	17.2
Grazed forage	3.1	3.8	3.4	3.3	2.7	3.1	2.7	1.6	1.7	1.5	1.4	1.2	1.1	1.4
Silage/hay	4.5	4.7	4.7	4.8	8.1	9.4	10.1	6.0	5.8	6.0	6.0	10.2	10.1	11.7
Corn silage	2.3	3.2	2.5	2.3	2.8	4.6	0.0	2.7	3.6	2.8	2.6	3.0	4.1	0.0
Oat grain	—	—	0.0	—	—	—	—	—	—	0.0	—	—	—	—
Purchased corn grain	6.6	5.0	6.1	7.1	6.4	2.5	6.7	1.6	1.2	1.3	2.3	1.2	0.3	2.3
Purchased protein supplement	4.2	4.3	4.3	4.1	1.1	1.7	1.0	5.0	5.0	5.0	5.0	1.9	1.9	1.8
Forage portion of diet, %	48	56	51	48	65	81	63	61	64	61	58	73	87	76

[1]Base2005 = 2005 corn price; Base2008 = Base2005 + corn price increase; Base2008X = Base2008 + corn area expanded; +smgrn = Base2008 + small grain produced on marginal lands; +milk = Base2008 + 5% milk production increase; +PFM = Base2008 + precision feed management (high-quality forage production, high-forage diet, and reduction of dietary P); X+PFM = +PFM + corn area expanded; Grass+PFM = +PFM + corn fields converted to grass.

Table 4. Integrated Farm Systems Model-simulated economic outputs for all strategies[1]

Item	2005	2008	2008X	X+notill	X+cover	+smgrn	+milk	+PFM	X+PFM	Grass+PFM
R-farm, $/yr per cow										
Milk and animal income	3,318	3,955	3,946	3,946	3,946	3,946	4,146	3,946	3,946	3,946
Total production cost	2,883	3,642	3,567	3,558	3,612	3,563	3,695	3,224	3,163	3,243
machinery	591	591	618	618	621	607	592	606	632	538
fuel, electric, labor	281	425	424	417	424	417	428	468	483	486
storage facilities	57	57	57	57	57	57	57	66	66	71
seed, fertilizer, chemicals	85	113	124	124	171	124	113	234	255	238
purchased feed	720	1,307	1,195	1,193	1,190	1,209	1,356	701	578	761
animal facilities, other	1,149	1,149	1,149	1,149	1,149	1,149	1,149	1,149	1,149	1,149
Farm net return	435	313	379	388	334	383	451	722	783	703
W-farm, $/yr per cow										
Milk and animal income	2,453	3,011	3,030	3,031	3,030	3,030	3,151	3,031	3,031	3,030
Total production cost	2,348	2,948	2,937	2,931	2,953	2,898	2,992	2,685	2,591	2,692
machinery	571	571	577	577	578	588	571	594	602	572
fuel, electric, labor	232	330	337	331	339	328	331	377	392	373
storage facilities	36	36	37	37	37	37	36	71	73	79
seed, fertilizer, chemicals	142	197	208	208	222	211	197	387	399	396
purchased feed	549	996	960	960	959	916	1,039	438	307	454
animal facilities, other	818	818	818	818	818	818	818	818	818	818
Farm net return	105	63	93	100	77	132	159	346	440	338

[1]Base2005 = 2005 corn price; Base2008 = Base2005 + corn price increase; Base2008X = Base2008 + corn area expanded; X+notill = Base2008X + no-till management on corn crops; X+cover = Base2008X + cover crop management on corn crops; +smgrn = Base2008 + small grain produced on marginal lands; +milk = Base2008 + 5% milk production increase; +PFM = Base2008 + precision feed management (high-quality forage production, high-forage diet, and reduction of dietary P); X+PFM = +PFM + corn area expanded; Grass+PFM = +PFM + corn fields converted to grass.

Table 5. Integrated Farm Systems Model-simulated environmental outputs for all strategies [1]

Item	2005 and 2008	2008X	X+notill	X+cover	+smgrn	+milk	+PFM	X+PFM	Grass+PFM
R-farm									
P imported, kg/ha	18.0	17.3	17.3	18.2	17.7	18.8	9.8	9.0	9.7
P exported, kg/ha	9.3	9.2	9.2	9.2	9.2	9.6	9.6	9.4	9.2
P balance, kg/ha	8.7	8.1	8.1	9.0	8.5	9.2	0.2	−0.4	0.5
Manure produced, t	282	290	290	290	285	287	289	288	286
P in manure, kg	1,974	1,992	1,992	1,992	1,983	2,034	1,495	1,490	1,492
Total sediment loss, t	686	874	275	378	713	684	687	868	230
Total soluble P, kg	55	57	59	60	57	56	47	48	46
Total sediment-bound P, kg	286	348	164	262	301	286	282	338	136
Sediment loss from corn, t	468	651	57	224	468	468	468	488	0
Sediment-bound P from corn, kg	158	219	35	133	158	158	156	212	0
N balance, kg/ha	104	100	100	125	97	105	149	156	171
N leaching, kg/ha	16	14	15	12	14	16	19	22	23
N in leachate, mg/L	4.7	4.1	4.1	3.2	4.0	4.7	5.6	6.4	6.6
W-farm									
P imported, kg/ha	9.4	9.3	9.3	9.3	8.8	9.9	5.3	4.8	5.0
P exported, kg/ha	4.1	4.5	4.5	4.5	4.2	4.3	4.4	4.4	4.4
P balance, kg/ha	5.3	4.8	4.9	4.9	4.6	5.6	0.9	0.4	0.6
Manure produced, t	137	138	137	137	139	136	142	141	142
P in manure, kg	870	882	864	876	870	881	661	656	661
Total sediment loss, t	381	444	287	295	405	381	364	428	227
Total soluble P, kg	36	37	40	39	39	36	32	33	29
Total sediment-bound P, kg	185	209	154	174	198	184	173	198	120
Sediment loss from corn, t	144	207	50	59	144	144	144	144	0
Sediment-bound P from corn, kg	59	84	29	49	59	59	58	58	0
N balance, kg/ha	103	101	101	105	103	104	184	181	195
N leaching, kg/ha	18	15	15	13	18	18	20	20	20
N in leachate, mg/L	5.1	4.1	4.1	3.3	5.0	5.0	6.1	6.0	6.0

[1]Base2005 = 2005 corn price; Base2008 = Base2005 + corn price increase; Base2008X = Base2008 + corn area expanded; X+notill = Base2008X + no-till management on corn crops; X+cover = Base2008X + cover crops management on corn crops; +smgrn = Base2008 + small grain produced on marginal lands; +milk = Base2008 + milk production level increased by 5%; +PFM = Base2008 + precision feed management (high-quality forage production, high-forage diet, and reduction of dietary P); X+PFM = +PFM + corn area expanded; Grass+PFM = +PFM + corn fields converted to grass.

W-farm, respectively. These reductions were achieved by feeding 2.4 and 1 kg/d of on-farm–produced oats. In this study, it was observed that there was not much difference in milk production whether cows were fed corn or a mixture of corn and oats as the energy grain portion of the diet. However, this study also does not suggest that oat grains can completely replace corn grain feed as the energy value of oats is less than that of corn grain (Table 2). Rather, this study stresses the potential of oats grown in marginal lands as a supplemental feed to reduce the amount of corn grain needed to balance the diet.

With increased milk production (+milk), increased corn grain was needed in both farms' diets to fulfill the increased energy requirements. The increase in corn grain consumed per cow that was needed to achieve a 5% increase in milk production was smaller for R-farm than W-farm. Because the Base2008 forage quality on R-farm was relatively better than on W-farm (Table 2), cows could most likely make more milk on forage in R-farm than on W-farm in +milk. The diets in R-farm also show a small increase in forage consumption in +milk compared with Base2008, whereas diets in W-farm did not. Also, the cows in W-farm were fed more protein supplement in the Base2008 (Table 3). Thus, more corn grain was added into the W-farm diet to provide the additional carbohydrate needed for meeting the increased milk production level.

The PFM management practices of feeding a high-quality, high-forage diet and reducing dietary P levels affected the farms to different extents as a result of their individual baseline daily feed compositions. Implementing the PFM program increased average forage to concentrate (**F:C**) ratios from 48:52 (Base2008) to 64:36 (+PFM) for R-farm across the winter and non-winter feeding periods (Table 3). This is a 35% increase in forage, mainly in high-quality grass hay, and a total decrease of purchased corn grain and supplements of 28%. For W-farm, adding PFM management increased the F:C ratio by about 47%, from 61:39 to an average of 77:23, resulting in an average decrease of 54% in total purchased grain and supplements. Overall, changes were slightly more moderate in the winter for R-farm and in the non-winter for W-farm. The increases in corn silage for the PFM scenarios in W-farm may have been because of the need for more carbohydrate by rumen microbes in order for them to utilize the greater amounts of ruminally available N provided by the increased intake of hay crop silage.

When additional corn silage was produced in conjunction with PFM practices (high-quality, high-forage, and reduced dietary P), more on-farm–produced corn silage was available to be fed. Thus, less corn grain was purchased in X+PFM than in +PFM, and forage feeding rates were increased. The X+PFM scenario consisted of high-forage diets with average F:C ratios of 80:20 and 88:12 for R-farm and W-farm, respectively, across the winter and non-winter feeding periods. Also, to achieve modeled milk production levels, IFSM simulated slightly greater total DMI as the forage feeding rate increased in X+PFM.

In contrast, in Grass+PFM (when the baseline corn area was converted to grass in addition to the PFM practices of +PFM), F:C ratios dropped a few percentage points below those of +PFM. In this case both farms were required to supplement their herds' diets with more purchased corn grain in order maintain the same milk production while offsetting dietary energy lost by reducing corn silage feed.

The R-farm, which was feeding a relatively lower percentage of forage in +PFM than the W-farm, purchased about 4 kg/d per cow less corn grain when producing additional corn silage (X+PFM) but only needed to purchase about 0.4 kg/d per cow more grain when switching to all-grass production (Grass+PFM). The W-farm was more evenly balanced in the changes in dietary energy needed to go from +PFM to X+PFM (decrease corn grain by 1 kg/d per cow) or Grass+PFM (increase corn grain by 0.9 kg/d per cow).

Economic Impacts

Rising feed prices have an adverse effect on the dairy farm's gross profitability. In 2005, purchased feed accounted for 25 and 23% of total production costs on R-farm and W-farm, respectively (Table 4). For R-farm, purchase of corn grain feed, protein, and other feed supplements (including mineral P, salts, and vitamins) accounted for 40, 52, and 8%, respectively, of total purchased feed costs. For W-farm, purchase of corn grain feed, protein, and other feed supplements made up 14, 71, and 15%, respectively, of total purchased feed costs. Hence, a price change for any of these feed components can significantly affect dairy farm profit margins.

Because of current price increases of farm production factors including feed, fuel, and fertilizers (as modeled by Base2008), the farms' annual net profits were predicted to decline by 28% ($122/cow) and 40% ($42/cow) for R-farm and W-farm, respectively, despite the higher milk prices. Annual net income obtained from selling milk at a higher price increased by $637/cow for R-farm and $558/cow for W-farm (Table 4); however, losses in net profits resulted because of the increased cost of production of R-farm ($759/cow) and W-farm ($600/cow). Of the total increases in production cost, the cost increases of supplemental feed accounted for 77% for R-farm and 75% for W-farm. The remaining 23 and 25% increases in costs for these farms were due to increases of other costs of farm production including fuel and fertilizers.

The recent increase in corn grain price, driven by the growing demand for corn grain, was expected to greatly affect total feed costs and potential profits of the farms. On average, annual corn grain consumption by R-farm and W-farm was equivalent to 1.9 t/cow and 0.65 t/cow, respectively (Table 2). The \$115/t DM increase in corn grain prices, as modeled by Base2008, raised annual supplemental feed costs by \$220/cow for R-farm and \$75/cow for W-farm. Thus, increases in annual cost of corn grain accounted for 39 and 17%, respectively, of total increases in supplemental feed costs (Table 2). Overall, purchased feed costs for R-farm increased from 25% (Base 2005) to 36% of total production costs. Purchased feed costs for W-farm increased from 23% (Base2005) to 34% of total production costs.

The economic predictions in Base2008 reflect the expected losses of net income due mainly to increased feed costs. Increasing corn silage production (Base2008X) enabled R-farm and W-farm to reduce annual corn grain purchases, saving R-farm \$112/cow and W-farm \$36/cow in purchased feed costs. Despite additional farm operation costs required in Base2008X to produce additional corn silage, including purchased fertilizer, fuel, machinery, storage, and labor, net returns for Base2008X increased by \$66/cow for R-farm and by \$30/cow for W-farm compared with Base2008. These gains in net return, however, covered only 54 and 71% of the \$122/cow and \$42/cow losses predicted due to the corn price increase from Base2005 to Base2008, for R-farm and W-farm, respectively. Thus, expansion of land in corn production alone did not offset profit losses caused by increased prices for supplemental feeds and other costs of production including fuel and fertilizer prices. However, this assessment is limited by the availability of potentially suitable land for expanding corn production.

Imposing no-till management on corn fields that were previously conventionally tilled (X+notill) resulted in a slight increase in net return compared with Base2008X because of savings in fuel consumption, equipment, and labor (Table 4). On the other hand, growing cover crops on otherwise bare corn fields during the fall and winter seasons (X+cover) resulted in a decline in net return because of increased operation costs required for planting, mowing, and killing the cover crops. Because cover-crop herbicides are used sporadically in this region, the costs of herbicides were not included in the economic analysis for this scenario. However, when herbicides are used, the net returns are expected to be even less than those presented in X+cover.

Growing small grains on marginal lands increased annual net returns by \$70/cow for R-farm and \$69/cow for W-farm compared with Base2008, largely by reducing the amount of purchased grain feed supplement. This strategy may be particularly useful on northeastern United States farms on which there is some marginal land that may not be suitable for corn production but could be used for growing small grains.

Simulation of a 5% increase in milk production levels increased farm profitability by \$138/cow for R-farm and \$96/cow for W-farm annually, compared with Base2008. By managing the herds to realize higher milk production levels, net profits increased despite the need to purchase larger quantities of higher priced corn grain to meet the increased energy requirements of high-producing cows. This shows that farmers must also consider the price of milk and the production response from feeding corn at current prices. Overall, the model simulation showed that feeding corn could be profitable, even when corn is relatively expensive, if farmer preference and facilities allow for management changes necessary for the corresponding increased production response.

Annual net returns increased greatly for both farms, above those of Base2005, when PFM strategies were imposed along with higher prices of supplemental feed, fuel, and N-fertilizer conditions (+PFM). For each farm, +PFM predicted net returns above those of either Base2008 or Base2005 (Table 4). These increases in net return were achieved by 1) increasing forage productivity and the proportion of forage in the diet, which reduced the need for purchased feed, particularly protein supplements; and 2) reducing dietary P rations to NRC (2001) recommended levels, which decreased dietary P supplements. This strategy stays profitable as long as the costs of N fertilizer and additional farm operations required to increase grass forage productivity are lower than the costs of excess feed supplements. Results of this study showed that despite higher fertilizer N costs and the additional fuel needed to harvest grass multiple times, it was still more profitable to invest in high-quality forage than adopt the other alternative strategies studied.

The percentage of total feed costs spent on protein supplements is substantial: 52% for R-farm and 71% for W-farm in Base2005. Implementing PFM strategies often reduces protein supplement costs, counteracting other price increases that are expected to cause net losses in profit. This was demonstrated in +PFM for both farms, where the farm net returns increased almost 66 and 230% compared with Base2005, the scenario before costs of feeds, fuel, milk, and fertilizer price were adjusted.

In X+PFM, when farms produced more corn silage by expanding land in corn production, in conjunction with producing and using high-quality grass forages

(PFM), annual net returns continued to increase (Table 4). These results indicate that farms realize a greater economic benefit by adapting combined strategies of expanding corn production, increasing productivity of land already in forage production, feeding high-forage diets, and reducing excess P inputs. Particularly increasing productivity of land already in forage production could be economically beneficial in regions such as the northeastern United States where 1) availability of additional land suitable for corn production is limited but land suitable for high-quality grasses is much less limited, and 2) where more than half of the total purchased supplemental feed is protein concentrates.

When all baseline corn fields were switched to high-productivity grass (Grass+PFM), net returns decreased slightly compared with switching to +PFM for both farms. With no corn production, the fixed costs of owning corn production equipment as well as operational costs were eliminated. Machinery costs were lower in Grass+PFM than in +PFM for both farms. However, more corn grain concentrates were purchased in Grass+PFM than in +PFM. Hence, compared with +PFM, profitability decreased \$19/cow and \$7/cow for R-farm and W-farm under Grass+PFM.

Environmental Impacts

In Base2005 and Base2008 on each farm, corn silage accounts for about 8 to 9% of the cultivated crop area (Table 2) but 38 to 68% of the erosion and 32 to 55% sediment-bound P loss (Table 5). Expanding corn silage production by 3% of the cultivated crop area decreased cover and disrupted the soil surface for 4 additional hectares on R-farm and 3 additional hectares on W-farm. With the corn area expansion, corn silage accounted for 11 to 12% of the cultivated crop area but 47 to 74% of the erosion and 40 to 63% sediment-bound P loss (Table 5). This demonstrates the significant need for management strategies on corn fields (with or without expansion) to control the high sediment and sediment-bound P losses.

Implementing no-till (X+notill) on R-farm corn fields controlled 91% of the erosion that would have occurred from the corn production fields. As a result, 84% less sediment-bound P was lost from corn fields by implementing a no-till strategy. For W-farm, the no-till strategy controlled 76% of the erosion and 65% of the sediment-bound P from the corn fields.

Applying a winter rye cover to the corn fields notably controlled both erosion and sediment-bound P loss by combining with the corn to provide a year-long surface cover (X+cover). However, both the corn and rye were conventionally tilled in this scenario, to provide a clearer comparison among scenarios. Thus, the sediment losses from X+cover were not as well controlled as in X+notill.

Expanding cropped area with oat grain (+smgrn) instead of corn silage increased erosion only slightly from the baseline. Despite the larger amount of land placed into oats than expanded corn for each farm, the oat crop provides a better surface cover than does the corn. Additionally, the most arable land in these farms is typically given to the corn, replacing grass lands when necessary, and the more marginal lands were selected for oats. Thus, the soil lost from the oat crops is likely to be of a poorer quality than that lost from corn crops.

Total erosion from R-farm's 12 ha each of corn and oats under +smgrn was 21 t/ha, a 6% increase in erosion from the 12 ha of corn in Base2008 but 20 t/ha less than from the 16 ha of corn in Base2008X. Total sediment-bound P lost from the total 24 ha of corn and oats on R-farm was 7 kg/ha, 9% greater than in Base2008. Under +smgrn, the 8 ha each of corn and oats of W-farm experienced 11 t/ha erosion, a 19% increase from the 8 ha of corn in Base2008 but 8 t/ha less than from the 11 ha of corn in Base2008X. Total sediment-bound P losses from the total 16 ha of corn and oats in +smgrn for W-farm were 5 kg/ha, a 22% increase from the baseline rate.

The 3 PFM-based scenarios reduced P in manure by about 2 kg of P/t of manure compared with all baseline scenarios, because at least 45% less P was imported into the farm. As a result, the P balance of R-farm was predicted to increase by 0.2 kg/ha under the nonexpanded PFM practice (+PFM) and by 8.7 kg/ha in Base2008. Under the expansion of corn land (X+PFM), PFM practices actually enabled R-farm to achieve a negative P balance (−0.4 kg/ha). The baseline P balance of 5.3 kg/ha on W-farm dropped to 0.9 and 0.4 kg/ha under PFM practices with nonexpanded and expanded corn land, respectively. The ability of the PFM strategies to bring the farms nearly into balance with regard to P imports and exports results in minimum P losses in runoff and erosion. On both farms the 2 corn-growing, PFM-based scenarios (+PFM and X+PFM) reduced or kept constant the sediment, sediment-bound P, and soluble P losses from the corn fields and the farms as a whole compared with their respective non-PFM strategies.

Using PFM and converting corn areas to all grass (Grass+PFM) reduced total sediment losses by 67% for R-farm and 38% for W-farm compared with the PFM strategy with corn (+PFM). In the same comparison, total sediment-bound P losses decreased by 52% for R-farm and 31% for W-farm.

Although change in the overall N balance from Base2008 to either Base2008X or X+notill was minimal on each farm, N leaching decreased by 2 to 3 kg/

ha on each farm because expanded corn land provided more crop area for spreading manure and more crop that could benefit from manure-N. With the addition of the cover crop (X+cover) and application of the corresponding necessary fertilizer, the N balance increased from Base2008X levels by 21 kg/ha for R-farm and 2 kg/ha for W-farm. However, the addition of the cover crop also increased crop N use, thus decreasing N leaching by about 4 kg/ha compared with Base2008.

The PFM-based corn scenarios increased N balance from the non-PFM scenarios by about 50 kg/ha (R-farm) and 80 kg/ha (W-farm). Nitrogen leaching increased by about 3 kg/ha compared with the baseline. Among all scenarios, the all-grass, PFM-based scenario (Grass+PFM) caused the largest increases in the N balance from Base2008 (67 kg/ha for R-farm and 92 kg/ha for W-farm). In the PFM scenarios, particularly the all-grass scenario, N fertilizer was added to improve grass forage quality. With the implementation of these PFM-based managements, it is important to consider management practices to better match N availability to crop needs to control N leaching and increase efficiency of N use for all forage production levels.

Switching from conventional tillage to no-till (X+notill), adding a conventionally tilled cover crop (X+cover), or converting corn areas to all grass under PFM (Grass+PFM) reduced both erosion and sediment-bound P losses when compared not only to the basic corn-expansion strategy (Base2008X), but also to the original land area modeled in Base2005 and Base2008. Of these 3 alternatives, the expanded corn with no-till (X+notill) also reduced N leaching and the P and N farm balances compared with the expanded or nonexpanded baselines.

CONCLUSIONS

Whole-farm modeling with IFSM on both a small (100 cows) and a medium-sized (100 to 199 cows) New York State dairy farm showed that expanding land for corn silage to counteract rising corn grain prices does not sufficiently offset the increased production costs and also greatly increases erosion and sediment-bound P losses. Implementations of no-till and cover-crop management on existing and expanded corn fields reduced soil and water degradation. The PFM practices improved the farm P balance by minimizing P imports. This led to less excess P in manure and fertilizer, which in turn decreased erosion and sediment-bound P losses compared with when PFM was not used. In addition, PFM improved farm profitability by providing the cows with higher quality grass forage and reducing purchases of dietary protein and P supplements. Alternatives such as growing additional small grains on marginal lands and increasing milk production levels also demonstrated potential for increasing farm profitability but did not minimize the farm P balance or improve economic efficiency by producing higher quality forage on existing forage crops.

Overall, it is crucial that conservation measures such as no-till and cover cropping be implemented on new or existing corn lands as these areas provide high potential for P losses through runoff. No-till small grains on marginal lands, in place of expanded corn silage lands, may be more profitable and more environmentally friendly on some farms. In all cases, increased use of PFM practices appears beneficial for both the farmer and the environment. Although alternatives that would likely provide the largest net profit were evaluated one at a time to better quantify their individual effects, combinations of these strategies are recommended whenever feasible.

The alternatives studied in this paper are not by any means the only options. For example, as long-term milk to feed price ratios continue to decline, Northeastern dairy farmers may be able to supplement with imported dried distillers grains (i.e., grains remaining after ethanol production from corn grain). However, the scope of this paper falls short in assessing the details of this option. More research is needed to determine the potential role of imported dried distillers grains on northeastern US dairies and issues related to the nutritional quality, cost variability, and contribution to the final composition of the feed ration of dried distillers grains.

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